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CERTAIN RESULTS OF THE MEDICO-BIOLOGICAL INVESTIGATION CONDUCTED IN THE GEMINI AND APOLLO PROGRAMS: CHANGE IN WEIGHT AND INDICES OF THE CARDIOVASCULAR SYSTEM IN ASTRONAUTS

V. I. Kopanev and Ye. M. Yuganov

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16. Abstract

It was found that the weight of the astronauts decreased during flight and was rapidly restored afterward (1-2 days). The mechanism of these changes is governed primarily by phenomena associated with dehydration of the organism. During postflight examination of the astronauts, a decrease in the orthostatic stability was observed as the result of the action of weightlessness. Following flights on which astronauts landed on the Moon, there was less evidence of orthostatic disturbances. The changes that were observed involving the cardiovascular system constituted accommodative reactions to unusual spaceflight conditions.

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CERTAIN RESULTS OF THE MEDICO-BIOLOGICAL INVESTIGATION CONDUCTED IN THE GEMINI AND APOLLO PROGRAMS: CHANGE IN WEIGHT AND INDICES OF THE CARDIOVASCULAR SYSTEM IN ASTRONAUTS

V. I. Kopanev and Ye. M. Yuganov

A large body of data has been collected in recent years on the influence of spaceflight factors on the human organism. We need only mention the successful completion of the Soyuz Program in the USSR and the Apollo Program in the USA. However, there are not very many discussions of the results of the flights, particularly those of the American astronauts (Kas'yan et al., 1967; Gazenko et al., 1968; Vasil'yev et al., 1969). /629*

In view of the program for joint efforts by Soviet and American researchers in the conquest of space, we have attempted to summarize the data on the results of the medico-biological studies carried out in the Gemini and Apollo Programs.[1]

As we know, between 1965 and 1972 the United States made ten manned space flights in the Gemini Program and eleven in the Apollo Program. During these seven years, there were 31 men in space, 13 more than once: 8 twice, 4 three times (C. Conrad, T. Stafford, D. Scott, E. Cernan) and 2 four times (J. Young, J. Lovell). Some of the data on the flights of the American astronauts are shown in Table 1.

An analysis of the data in Table 1 clearly shows that the Gemini Program was aimed at the solution of a number of problems: investigation of the possibility that man could stay in outer space for a number of days, development of

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[1]In this work, we used translations prepared by D. Yu. Gol'dovskiy, Yu. B. Yeliseyenkov, L. L. Zhurèn, Ye. P. Kostrub, A. Z. Mnatsikan'yan, E. M. Panova, G. Ya. Tverskaya, Zh. N. Yaroslavtsevaya, N. L. Kolesnikova, Ye. V. Titova and R. K. Konovalovaya.

* Numbers in the margin indicate pagination in the foreign text.

docking techniques under weightless conditions using an unmanned satellite target, performance of experiments involving space walks by the astronauts, and the performance of working operations under these conditions, the performance of various scientific and technical (including medico-biological) experiments, testing of onboard apparatus and life-support systems.

The Apollo Program was intended to land astronauts on the Moon, carry out scientific and technical experiments, collect samples of lunar soil and return the spacecraft crews to Earth. The Gemini and Apollo Programs were closely linked. The goals and tasks of the Apollo Program could only be solved /633 successfully in the event that all of the problems faced by the participants in the Gemini Program were solved, since in order to land on the lunar surface it was essential to solve problems related to rendezvous and docking of spacecraft, the scope of possible working operations for man in deep space was clarified, the degree of "harmfulness" of prolonged action of spaceflight factors on the human organism (especially weightlessness), the onboard life-support systems were tested, and several other problems were solved.

There are several very important aspects of the evaluation of the action of spaceflight factors on the organism of astronauts in these programs: 1) the duration of exposure to weightlessness did not vary considerably from one case to the next (in the Gemini program it was approximately 0.4 to 14 days and in the Apollo program -- 5-13 days); 2) the participation of not one but two or three astronauts in the flight, i.e., in all cases the flights were carried out by crews, which was undoubtedly of great significance; 3) the maintenance of approximately the same work, rest and eating schedule for the flight crew on most flights; 4) a certain degree of uniformity in carrying out individual work operations: rendezvous with the object, docking with it, making a space walk, etc. All of this enabled us to view the medico-biological changes in the /634 astronauts during the flights in the Gemini and Apollo programs from the same standpoint as the reactions of an organism to unusual external conditions of approximately the same biological significance. Of course, in analyzing the materials we did not forget certain specific characteristics that were associated with flights in each program. Thus, in contrast to the flights in the Gemini program, beginning with the flight of the Apollo-11, the astronauts were subjected to the action of lunar gravitation (1/6 of that on Earth) during the flight for 21-71 hours (Berry, 1969; Slater, 1971 et al.).

The gas medium in the spacecraft cabin of the Gemini was composed of pure oxygen while the cabins of some of the Apollo spacecraft contained 60% oxygen and 40% nitrogen during the launching stage and of oxygen with small amounts of nitrogen (1-3%) during all subsequent stages of the flight (Berry, 1969, 1970, 1971; Lomonaco, 1969, 1970 et al.). The cabin of the Gemini spacecraft was small and cramped, and the astronaut had limited ability to move around, while the cabins of the Apollo spacecraft were more roomy and the astronauts could move around and perform physical exercises. There were certain differences in the programs of the scientific and technical experiments as well. While medical and biological experiments were provided during the Gemini flights, they were completely excluded during the flights in the Apollo program (Berry, 1970, 1971). We took all of these details into account in evaluating specific changes in the state of health which occurred in the astronauts during the flight or afterward.

Change in body weight. One of the important parameters of the condition of the astronauts in flight was the body weight. It was found that after each space flight the astronauts lost weight (Berry, 1970; 1971; Davis, 1970). Thus, during the flights in the Gemini program the astronauts lost approximately 3-8% (2-4 kg) of their weight, as recorded prior to the launch. After brief flights, these losses were made up during the first 12 to 24 hours following splashdown. In the case of the 14-day flight aboard the Gemini-7, the crew members continued to show a weight loss for more than 24 hours after the flight.

The data on the nature of the changes in this parameter in the Apollo astronauts are shown in Table 2.

As we can see from Table 2, in all of the astronauts the weight returned to normal during the first 24 hours following return to Earth. This clearly indicates that the weight loss was primarily due to fluid losses and a positive water balance during the first hours following completion of the flight. Prior to the Apollo-14 flight it was assumed that extracellular fluid losses constituted a large portion of the total moisture deficit in the organism. It was felt that water loss was due primarily to interstitial fluid. However, the results of the evaluation of water exchange that were obtained during the Apollo-14 flight showed (Berry, 1971) that the water deficit was caused by a drop in intracellular fluid (Table 3).

As we can see from Table 3, the quantity of extracellular fluid remains practically constant. From this we can see that the total water deficit in the organism was due to the decrease in the volume of intracellular fluid. Berry (1971), in analyzing these data, expresses certain doubts. He feels that such a conclusion requires further confirmation. The possibility cannot be completely excluded that the weight loss during flight is also related to loss of body mass. One would have to agree fully with this, taking into account the nature of the changes in the blood indices, as well as the mineral and electrolyte exchange. Soviet investigators also have a tendency to link the weight loss of cosmonauts to dehydration of the organism during flight (Sisakyan, Yazdovskiy, 1962, 1964; Parin et al., 1967; Vorob'yev et al., 1969, 1970; Nefedov et al., 1969, 1972; Balakhovskiy et al., 1971; Kozyrevskaya et al., 1972). According to the data, all cosmonauts showed a weight loss of 2-4 kg, /636
a decrease in renal excretion of electrolytes, as well as osmotically active substances. Following flights lasting up to five days, recovery of weight occurred in the course of 2-3 days, while these periods were longer for more prolonged flights. A common feature of flights lasting more than three days was a change in kidney function that took the form of a high excretion of sodium, potassium, chlorine and calcium following a water load. The searchers noticed one curious phenomenon -- the lack of a sensation of thirst in the cosmonauts during the flight, a feeling that is so characteristic of exsiccoses. I. G. Popov et al. (1972) explains this from the standpoint of the development of a process of adaptation to weightless conditions. In their opinion, dehydration is a normal reaction to the change in gravitational effects; consequently, when the sense of thirst is depressed, the organism does not suffer any disruption of the homeostatic conditions through additional intake of water from outside.

TABLE 1. CERTAIN DATA ON THE FLIGHTS OF ASTRONAUTS IN THE GEMINI AND APOLLO PROGRAMS

Spacecraft	Astronauts	Date of Flight	Length of Flight			Principal Tasks of the Flight and Their Performance
			Days	Hrs.	Min.	
			The Gemini Program			
Gemini-3	Virgil Grissom - SC** John Young - C**	3/23/65	--	4	53	Investigation of a prolonged stay by man in outer space*, testing of onboard equipment*, maneuvering in orbit. Tasks carried out.
Gemini-4	James McDivitt - SC, Edward White - C	6/3/65	4	0	56	Rendezvous with an object in orbit, space walk. First task partially carried out. Approach to second stage of carrier rocket carried out, maintaining a distance of approximately 600 m. Cosmonaut E. White made a space walk lasting 20 minutes. He moved around using a tether and a jet device.
Gemini-5	Gordon Cooper - SC, Charles Conrad - C	8/21/65	7	22	55	Development of onboard equipment, rendezvous with object in orbit. Latter task not carried out.
Gemini-7	Frank Borman - SC, James Lovell - C	12/4/65	13	18	35	Rendezvous with object in orbit, group flight. Tasks carried out. Craft came within 1-30 m of each other and flew together for 5.5 hours.
Gemini-6A	Walter Schirra - SC, Tom Stafford - C	12/15/65	2	1	51	Same.
Gemini-8	Neil Armstrong - SC, David Scott - C	3/16/66	--	10	42	Rendezvous with object in orbit. Task accomplished. First docking with "Agena" rocket.
Gemini-9	Tom Stafford - SC, Eugene Cernan -C	6/1/66	2	0	21	Rendezvous with object in orbit, docking, space walk. Second task not carried out. Cernan was in deep space for 2 hours and 5 minutes.
Gemini-10	John Young - SC, Michael Collins - C	7/18/66	2	22	46	Rendezvous with object in orbit, docking with it, use of the engine of the "Agena" rocket to move to a higher orbit, space walk. All tasks carried out completely with the exception of the last; it was carried out partially. Collins was in deep space for 38 minutes.

TABLE 1 (Continued)

Spacecraft	Astronauts	Date of Flight	Length of Flight			Principal Tasks of the Flight and Their Performance
			Days	Hrs.	Min.	
Gemini-11	Charles Conrad - SC, Richard Gordon - C	9/12/66	2	23	17	Same as on the Gemini-10 flight, plus stabilization of the satellite and rocket connected by a cable. All tasks carried out, space walk -- partially. Instead of 107 minutes, Gordon was in deep space for 44 minutes.
Gemini-12	James Lovell - SC, Edwin Aldrin - C	11/11/66	3	22	35	Same as during the Gemini-11 flight. The use of the engine of the "Agena" rocket to shift the craft to a higher orbit was not carried out. Aldrin was in deep space for 2 hours and 10 minutes.
						The Apollo Program
Apollo-7	Walter Schirra - SC, Walter Cunningham - CMP***, Don Eisele - LMP***	10/11/68	10	20	9	First flight of Apollo spacecraft with men onboard. Flight in orbit around the Earth. Testing of command module, rendezvous with the final stage of the carrier rocket, maneuvering. Tasks carried out.
Apollo-8	Frank Borman - SC, James Lovell - CMP, William Anders - LMP.	12/21/68	6	3	0	Testing of the command module with injection into selenocentric orbit. Tasks carried out.
Apollo-9	James McDivitt - SC, David Scott-CMP, Russell Schwikert - LMP	3/3/69	10	1	0	Test of spacecraft in low geocentric orbit. Re-arrangement of modules, transfer of the LMP from the lunar module to the command module and back again by means of a space walk. Independent flight of the lunar module with 2 astronauts aboard. Tasks carried out with the exception of the space walk due to the illness of the LMP.
Apollo-10	Tom Stafford - SC, John Young - CMP, Eugene Cernan - LMP	5/18/69	8	0	3	Tests of regular craft with injection into selenocentric orbit. Independent flight of the lunar module around the Moon at an altitude of 15 km. Tasks carried out.

TABLE 1 (Continued)

Spacecraft	Astronauts	Date of Flight	Length of Flight			Principal Tasks of the Flight and Their Performance
			Days	Hrs.	Min.	
Apollo-11	Neil Armstrong - SC, Michael Collins - CMP, Edward Aldrin - LMP	7/16/69	8	3	18	Landing on the Moon. Activity on the surface to set up instruments and collect rock samples. Tasks carried out. Approximately 25 kg of lunar rock samples were collected. Armstrong and Aldrin conducted the EVA on the Moon. The total time of their stay on the Moon was 21 hours 36 minutes, with 2 hours and 10 minutes being spent on the surface.
Apollo-12	Charles Conrad - SC, Richard Gordon - CMP, Alan Bean - LMP	11/14/69	10	4	36	Landing on the Moon. Two lunar EVA's to set out instruments, collect lunar soil samples, remove parts of the Surveyor-III apparatus. Arranging for the exhausted launching stage of the LEM to fall back to the Moon. Tasks carried out. Conrad and Bean conducted the lunar EVA. The total time spent on the Moon was 31 hours and 31 minutes, with 7 hours and 55 minutes being spent on the lunar surface. Approximately 36 kg of rock were collected.
Apollo-13	James Lovell - SC, John Swigert - CMP, Fred Haise - LMP	4/11/70	5	22	54	Same as for the Apollo-12 flight. None of the tasks was carried out (except for allowing the last stage of the carrier rocket to fall to the Moon) due to the explosion of an oxygen tank on the way to the Moon.
Apollo-14	Allan Shepard - SC, Stuart Roosa - CMP, Edgar Mitchell - LMP	1/31/71	9	0	2	Same as for the Apollo-12 flight. All tasks carried out. Shepard and Mitchell landed on the Moon. The total time of their stay was 33 hours and 30 minutes, with 9 hours and 14 minutes being spent on the lunar surface. Approximately 43 kg of rock were collected.
Apollo-15	David Scott - SC, Alfred Worden - CMP, James Irwin, LMP	7/26/71	12	7	12	Landing on the Moon, Three EVA's on the surface, testing of the Lunar Rover, collection of rock samples, performance of a number of scientific-technical experiments. Tasks carried out. Astronauts Scott and Irwin landed on the Moon, tested the lunar core, and collected approximately 77 kg of rock. The total time spent on the Moon was 66 hours and 55 minutes, with 18 hours and 36 minutes spent in EVA.

TABLE 1 (Continued)

Spacecraft	Astronauts	Date of Flight	Length of Flight			Principal Tasks of the Flight and Their Performance
			Days	Hrs.	Min.	
Apollo-16	John Young - SC, Thomas Mattingly, CMP, Charles Duke - LMP	4/16/72	11	1	51	Same as for Apollo-15 flight. Tasks carried out. Astronauts Young and Duke landed on the Moon, tested the Lunar Rover (travelling 27.1 km), and selected 95 kg of soil. The total time of their stay on the Moon was 71 hours and 2 minutes, with 20 hours and 14 minutes spent in EVA.
Apollo-17	Eugene Cernan - SC, Ronald Evans, CMP, Harrison Schmidt - LMP	12/7/72	12	16	31	Same as for Apollo-15 flight. Tasks carried out. Astronauts Cernan and Schmidt made three lunar EVA's, drove around in the Lunar Rover (36.2 km) and collected samples of lunar soil. The total time of their stay on the Moon was 75 hours.

* These problems were solved on all subsequent flights in the Gemini and Apollo Programs.

** SC - Spacecraft Commander, C - Copilot.

*** CMP - Command Module Pilot, LMP - Lunar Module Pilot.

TABLE 2. CHANGE IN BODY WEIGHT OF THE APOLLO ASTRONAUTS IN COMPARISON WITH PREFLIGHT DATA

Spacecraft	Crew Members	Change in Body Weight Immediately After Flight		Change in Body Weight 24 Hours After Flight	
		kg	%	kg	%
Apollo-7	SC	- 2.5	- 3.2	+ 1.0	+ 1.3
	CMP	- 4.0	- 6.4	+ 1.4	+ 2.2
	LMP	- 3.2	- 5.1	+ 2.2	+ 3.5
Apollo-8	SC	- 3.5	- 5.1	+ 1.1	+ 1.6
	CMP	- 3.1	- 4.5	+ 0.3	+ 0.4
	LMP	- 1.6	- 2.8	+ 0.2	+ 0.3
Apollo-9	SC	- 2.1	- 3.3	+ 1.1	+ 1.7
	CMP	- 3.3	- 3.2	+ 3.4	+ 4.8
	LMP	- 2.4	- 3.8	+ 1.7	+ 2.6
Apollo-10	SC	- 0.8	- 1.1	+ 0.8	+ 1.1
	CMP	- 2.0	- 3.0	+ 0.4	+ 0.6
	LMP	- 4.0	- 5.8	+ 0.8	+ 1.2
Apollo-11	SC	- 3.2	- 4.7	+ 2.4	+ 3.7
	CMP	- 2.8	- 4.2	0.0	0.0
	LMP	- 0.4	- 0.6	+ 1.6	+ 2.4
Apollo-12	SC	- 1.7	- 2.8	+ 0.8	+ 1.4
	CMP	- 2.9	- 4.7	+ 1.6	+ 2.7
	LMP	- 5.0	- 8.2	+ 1.2	+ 2.1
Apollo-13	SC	- 5.6	- 8.1	--	--
	CMP	- 4.4	- 5.6	--	--
	LMP	- 2.6	- 4.2	--	--
Apollo-14	SC	+ 0.4	+ 0.5	+ 0.4	+ 0.6
	CMP	- 4.8	- 7.2	+ 2.8	+ 4.8
	LMP	+ 0.4	+ 0.5	+ 0.4	+ 0.6
Apollo-15	SC	- 0.5	- 0.7	+ 0.4	+ 0.5
	CMP	- 1.2	- 1.9	+ 0.8	+ 1.3
	LMP	- 2.2	- 3.4	+ 2.0	+ 3.2
Apollo-16	SC	- 3.0	- 4.3	+ 1.4	+ 2.0
	CMP	- 2.6	- 4.0	+ 1.2	+ 1.9
	LMP	- 2.6	- 4.1	+ 1.0	+ 1.8

Note: SC - Spacecraft Commander; CMP - Command Module Pilot; LMP - Lunar Module Pilot; (-) - Decrease, (+) - Increase.

TABLE 3. CHANGE IN FLUID VOLUME IN THE ORGANISM FOR THE APOLLO-14 ASTRONAUTS 24 HOURS AFTER THE END OF THE FLIGHT (IN % OF THE VALUES RECORDED AFTER THE FLIGHT)

Parameters	Method of Measurement	Spacecraft Commander	Command Module Pilot	Lunar Module Pilot	Control Subjects		
					1	2	3
Erythrocyte mass	Cr^{51}	- 1.7	- 9.1	- 4.0	+ 4.4	- 3.5	+ 0.3
Plasma volume	I^{125} albumin	+ 1.2	- 9.7	+ 0.1	+ 6.0	+ 6.1	+10.7
Extracellular fluid	SO_4	- 0.5	0.0	- 0.5	+ 4.2	- 2.5	+ 3.3
Total water	H_2^2O	- 1.9	+ 17.7	- 1.8	+ 1.6	- 2.1	+ 3.0
Intracellular fluid	Calculation	- 2.7	- 27.0	- 2.6	0.0	- 1.6	+ 2.9

The physiological mechanisms of dehydration of an organism under weightless conditions have been quite thoroughly studied as of the present time. The triggering mechanism is the decrease in the hydrostatic pressure of the blood, its redistribution and disruption of the volume space. As a result, there is a rush of blood to the large vessels in the chest, stimulation of the receptor formations in the large veins, and the development of compensatory reactions (Gauer et al., 1967; Gauer, 1971). Plasma loss develops, there is a drop in the total volume of circulating blood, the action of the antidiuretic hormone is reduced, the reabsorption of water and sodium in the kidneys is decreased and diuresis increases. A definite significance in the regulation of water-salt exchange is attributed to osmoreception and secretion of aldosterone which intensifies the reabsorption of sodium. In addition to the dehydration of the organism, as mentioned earlier, there is a decrease in thirst. As a result, the water-salt exchange is observed to return to a new level and the organism adapts to the modified conditions. Very strong support for some of the views stated above is provided by experiments which were performed on a monkey during the flight of the "Biosatellite-III" (Adey et al., 1971; Meehan et al., 1971). By catheterization of the arterial and venous beds, it was demonstrated that under weightless conditions there is an increase in central venous pressure. It rises by 2-3 cm water column in the right auricle, which is sufficient to cause compensatory fluid loss from the organism. In analyzing the results of the Gemini-7 flight, the authors of this paper drew conclusions concerning methods of adaptation to the factor of weightlessness. Clearly, there will be a gradual decrease in venous tone, an increase in the tensility of the venous system, and the blood will return to the peripheral parts of the body, resulting in a drop in the pressure in the central veins and development of regulatory mechanisms of water-salt exchange.

Changes involving the cardiovascular system. In the Gemini and Apollo programs, considerable emphasis was placed on the study of spaceflight factors and their effect on the cardiovascular system. The study was performed both during the flights and afterward. During the flights in the Gemini program, the electrocardiogram (EKG) was recorded with two leads and the arterial pressure was recorded as well (using the Krotkov method with a phonocardiographic sensor); in the Apollo program, the EKG was recorded. Before and after the flights, in both cases, a great many tests were performed to determine the orthostatic stability for the purpose of detecting a loss of training by the cardiovascular system. As the test, the researchers used the passive method of standing or decompression of the lower half of the body, produced by a gradual decrease in pressure (NPLB -- negative pressure on the lower half of the body). One of the reasons for the NPLB test was that it was intended for use in evaluating the orthostatic mechanisms and their training /637 on future flights aboard the Skylab Orbiting Station. Despite the differences in the tests, the physiological reactions to them were about the same (Johnson, 1971; Musgrave, 1971 and others). As an illustration, we can use the data from an examination of astronaut F. Borman before and after flights aboard the Gemini-7 and the Apollo-8 (Figure 1).

Indirect data on the state of the cardiovascular system were obtained likewise during the measurement period in the astronauts during the pre- and postflight periods to determine the perimeter of the shin and the heart size (roentgenographic method).

In analyzing the data from the flights it was found that the parameters of the cardiovascular system (pulse frequency and EKG parameters) for all of the astronauts varied quite regularly: initially, even before the flight, there was a speeding up of the pulse which became even more significant during the time when the spacecraft was being injected into orbit, after which the pulse slowed down under weightless conditions, only to speed up again upon reentry into the dense layers of the atmosphere at splashdown. Approximately 60% of the astronauts who participated in the Apollo flights and were in a reclining position on their backs in a state of rest, showed an increase in pulse rate during the postflight examinations lasting 30-50 hours (Berry, 1973) (Table 4). A similar type of change was observed in the Soviet cosmonauts (Bayevskiy et al., 1964; Kas'yan et al., 1968; Vorob'yev et al., 1969, 1970 and others). In view of the fact that the pulse frequency did not increase in anesthetized animals under weightless conditions (Galkin et al., 1958), the tachycardia that was observed during the initial hours of the flight, in the opinion of the majority of investigators, is not the result of specific influence of weightlessness on the cardiovascular system. It is produced by the influence of accelerations on the active portion and the period of launching and neuro-emotional stress both during the prelaunch period and all during the flight.

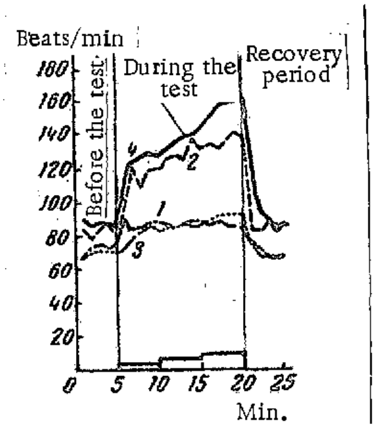

Figure 1. Change in Pulse Frequency (PF) in Astronaut F. Borman During a Test Involving Passive Standing at an Angle of 70° Before and After the 14-Day Flight Aboard the Gemini-7 and Under the Influence of Negative Pressure on the Lower Half of the Body (NPLB) with Values of 30, 40, 50 mm Hg, After the 6-Day Flight Aboard the Apollo-8: 1, PF before the flight aboard the Gemini-7; 2, PF after the flight aboard the Gemini-7; 3, PF before the Apollo-8 flight; 4, PF following the Apollo-8 flight.

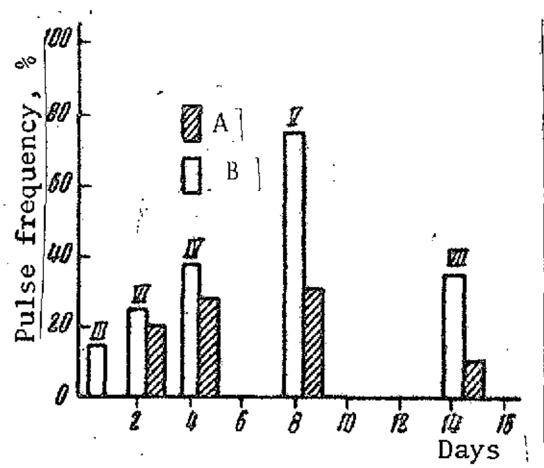

Figure 2. Change in Pulse Frequency at Rest (% of Data From Control Studies, Average Values) in the Gemini Astronauts and Subjects with Bed Rest as a Function of the Length of the Experiments: A, Experiments with bed rest; B, Space flights; Roman Numerals, Numbers of spacecraft.

An important role was also played under weightless conditions by the change in physical conditions -- the elimination of the hydrostatic blood pressure, resulted in disappearance of the weight of the blood, facilitation of the work of the heart and the marked decrease in pulse frequency. /638

TABLE 4. MAXIMUM LEVEL OF PULSE FREQUENCY (BEATS/MINUTE) IN SEVERAL ASTRONAUTS DURING SPACE FLIGHT

Spacecraft	Astronauts	In the Active Phase	Upon Entry Into The Dense Layers Of The Atmosphere During Landing
Gemini-3	V. Grissom	152	165
	J. Young	120	130
Gemini-4	J. McDivitt	148	140
	E. White	128	125
Gemini-5	G. Cooper	148	170
	C. Conrad	155	178
Gemini-6	W. Schirra	125	195
	T. Stafford	150	140
Gemini-7	F. Borman	152	130
	J. Lovell	125	134
Gemini-8	N. Armstrong	138	130
	D. Scott	120	90
Gemini-9	T. Stafford	142	160
	E. Cernan	120	126
Gemini-10	J. Young	120	110
	M. Collins	125	90
Gemini-11	C. Conrad	166	120
	R. Gordon	154	117
Gemini-12	J. Lovell	136	142
	E. Aldrin	110	137
Apollo-8	E. Anders	118	92
Apollo-9	J. McDivitt	145	110
	D. Scott	135	82
	R. Schwikert	95	82
Apollo-11	N. Armstrong	110	---
	M. Collins	99	---
	E. Aldrin	88	---

Note: During weightlessness, all of the astronauts showed a decrease in the frequency of cardiac contractions during weightlessness [sic]: after 3-5 hours, to 60-80 beats/minute, while after 36-48 hours it stabilized within the limits of 40-80 beats/minute, being minimal during sleep. In carrying out individual work operations inside the spacecraft or when the drive engines were switched on, the pulse briefly increased to 100-120 beats/minute.

If we analyze the data in Table 4, we are struck by the moderate nature of the increase in pulse frequency during the active stage of the Apollo flights in comparison with the Gemini flights. This is clearly due to the smaller values for the active accelerations and the greater confidence of the crew in the reliability of the technology and the safety of the flights. The fact that some of the astronauts were taking part in space experiments for a second time was also of definite significance. This is particularly clear in the case of an analysis of data from the examination of the Apollo-11 crew. All of the crew members aboard the Gemini flights had shown a greater increase in pulse frequency. Particular attention attaches to the question of the change of the pulse frequency of the astronauts at rest as a measure of their exposure to weightless conditions. Dietlein (1970) compared the pulse frequency (in a percentile relationship to the preflight data) during the Gemini flights of varying duration. He found that there was an almost linear increase in the parameters by the eighth day and a decrease by the 14th, which the author explains by the improvement of the schedule for work, rest and eating by the Gemini-7 crew members and mainly by the fact that for a large part of the flight the astronauts did not wear their space suits (Figure 2). Vallbona et al.,(1970) carefully studied the influence of spaceflight factors on the bioelectrical activity of the heart. Studying the EKG's recorded during the flights of the Gemini-4 and 7, they found that all of the astronauts exhibited considerable variation in the cardiac cycle parameters. They found a direct correlation in the nature of the changes of the EKG parameters to the frequency of the cardiac contractions. In a statistical analysis (method of regression, etc.) it was shown that the variations that were observed occurred in the area that was characteristic for normal healthy individuals. During the flight, several extrasystoles were observed, primarily during accelerations involved /639
in launching and splashdown. Arrhythmic contractions of cardiac muscle during flight were also found in a brief discussion of the results of the flight by astronauts D. Scott and D. Irwin aboard the Apollo-15.

Studies of arterial pressure, in the opinion of Berry (1967), failed to reveal any kind of regular phenomena. As the pulse increases, it also rose. During the flight aboard the Gemini-7, the maximum blood pressure for 14 days was 110-145 mm Hg, the minimum value was 50-80 and the pulse pressure was

50-90 mm Hg. A change in pulse pressure was observed as a function of exposure to weightless conditions which indicated hemodynamic changes (Figure 3).

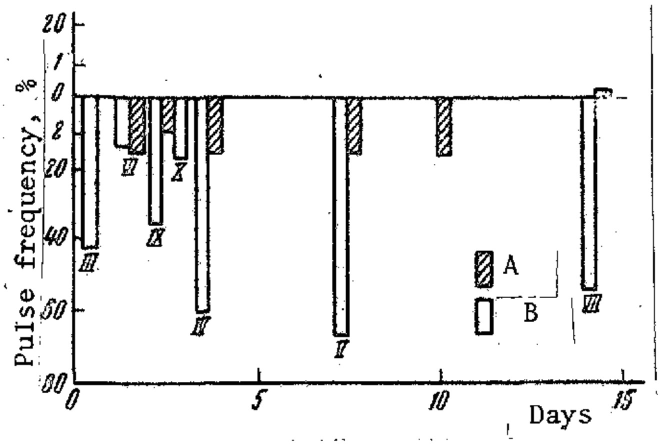

Figure 3. Change in Pulse Frequency at Rest (% of Data from Control Studies, Average Values) in Gemini Astronauts and in Subjects Exposed to Bed Rest as a Function of the Duration of the Experiments: A, Experiments with Bed Rest; B, Space Flights; Roman Numerals, Numbers of Spacecraft.

During the flight, the cardiovascular system was studied not only during the time the astronauts were at rest, but also while they were doing work: conducting space walks or EVA's on the lunar surface. As we know, in accordance with the program of the Gemini flights, five astronauts conducted space walks. They were subjected to these conditions and worked under them for a total of about six hours. The first space walk took place during the Gemini-4 flight. The pulse and respiration of astronaut White, who took the space walk, were recorded (Figure 4).

As we can see from Figure 4 the pulse frequency was significant. At certain times it reached 176 beats/minute (when closing the hatch). Approximately the same kind of data were recorded for E. Cernan. When he opened the hatch, Cernan's pulse reached 155 beats/minute; after 30 minutes it had fallen to 125, after which it remained between 130 and 170 beats/minute. The maximum frequency was also recorded on closing the hatch (180 beats/minute). These important physiological changes, it turned out, were caused primarily by external factors: insufficiencies in the life-support systems for the space suits, faulty characteristics in the fastening system, problems in the organization of the schedule and rest of the astronauts. All of this was taken into account on subsequent EVA's and slightly different data were obtained. Physiological changes were quite moderate (Figure 5). Similar results were obtained during the space walks of R. Schwikert, T. Mattingly and the other astronauts who took part in the Apollo program.

The American astronauts conducted repeated EVA's on the lunar surface. They total more than 70 hours. One is struck by the remarkable moderation of the changes in pulse frequency. It did speed up, but in most cases the changes were not significant. Thus, in the first men to walk on the Moon the pulse frequency during the EVA was an average of 90-100 beats/minute, with the maximum value in Armstrong being 160 beats/minute and 125 in Aldrin (Figure 6). /640

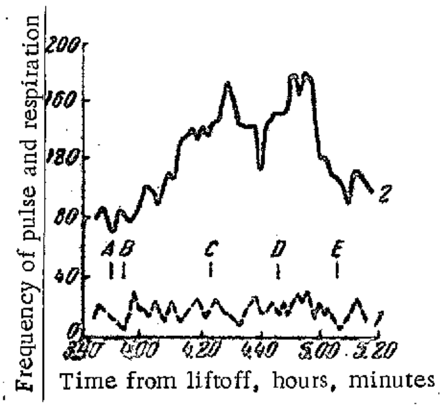

Figure 4. Pulse Rate and Respiration in Astronaut E. White During Space Walk: 1, Breathing Rate; 2, Pulse Frequency; A, Opening of Hatch; B, Receiving Commands to Leave the Cabin; C, Leaving the Cabin; D, Returning to the Cabin; E, Closing the Hatch.

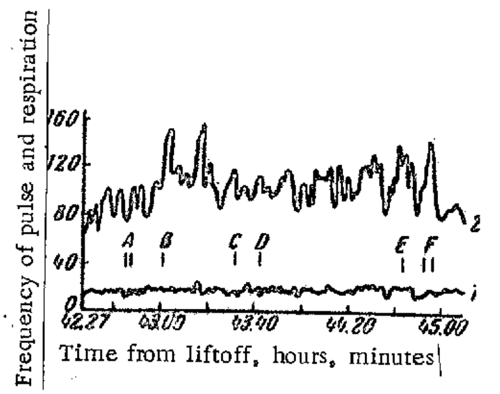

Figure 5. Pulse Frequency and Respiration in Astronaut E. Aldrin During Space Walk: 1, Respiration Rate; 2, Pulse Frequency; A, Opening the Hatch; B, Fastening the Lanyard to the Hull of the Satellite; C and D, Activity in Deep Space; E, Return to the Cabin; F, Closing the Hatch.

During the first EVA by astronauts C. Conrad and A. Bean, the average pulse frequency for the former was 105 (80-150) beats/minute while for Bean it was 121 (82-151). They felt excellent. It is true that during the second EVA the changes were more pronounced. The pulse varied from 165-170 beats/min. /641 Fatigue was clearly making itself felt. However, the changes in pulse were moderate in the case of A. Shepard and E. Mitchell during their EVA on the Moon with the Apollo-14. In Shepard it varied from 90-100, while for Mitchell it was 100-120 beats/minute.

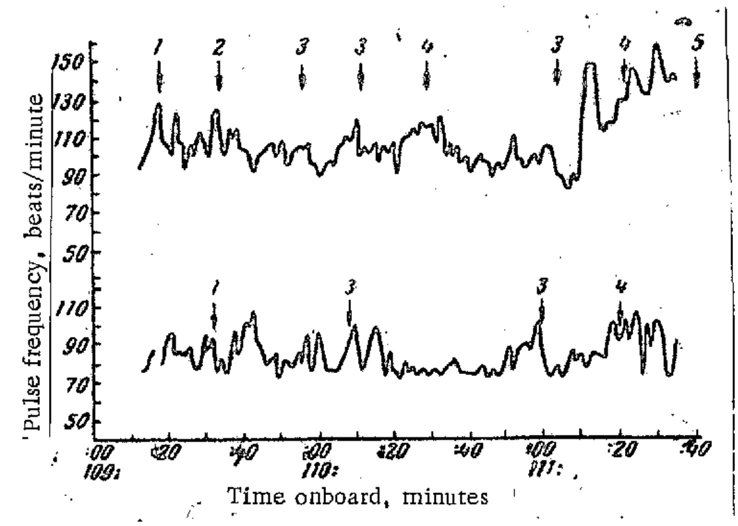

Figure 6. Change in Pulse Frequency in Astronauts Armstrong (Upper Graph) and Aldrin (Lower Graph) During the First Walk on the Lunar Surface: 1, Stepping on the Surface of the Moon; 2, Collecting the Contingency Sample of Lunar Soil; 3, Setting out Instruments; 4, Collecting the Main Sample of Lunar Soil; 5, Completion of Work in Space.

In this connection, particular interest surrounds the results of the work of V. S. Georgiyevskiy et al. (1972) who studied the influence of a 5-day orbital flight on blood circulation during performance of physical work of moderate intensity -- 100 W (162 kg/minute). It was found that after the flight there was a deterioration of the reactions involving the cardiovascular system: speeding up of the pulse, slowing down of its normalization following the test, etc. However, the hemodynamic changes did not go beyond normal limits. Functional reserves were completely retained.

In discussing the physiological mechanisms of such changes, American researchers link them primarily to the physical work which the astronauts performed in flight. This is obviously valid. However, it is also worth noting the remark made by Berry (1970) who analyzed the results of the lunar experiments and pointed out that in many cases the pulse speeded up when the acceleration could not be attributed to work. He suggests the existence of some other factors that are still unknown.

On the basis of the data from the space experiments, R. M. Bayevskiy and O. G. Gazenko (1964) and V. V. Parin et al. (1967) distinguished several phases in the nature of the changes of the hemodynamic parameters under weightless conditions: transitional reactions of a "relief" type and reactions involving stabilization that reflected a predominance of parasympathetic effects. Without denying the existence of these phases, A. M. Genin and I. D. Pestov (1971) feel that prolonged exposure to weightless conditions probably is accompanied by the development of reactions of a sympathetic nature. Thus, on the 18-day flight of the Soyuz-9 a tendency toward increased pulse frequency was observed during the last week of the flight (Vorob'yev et al., 1970).

The first indications that the shift from weightlessness to terrestrial gravitation is a rather difficult process came to light after the first orbital flights (Link, 1965). The astronauts who had flown in the Mercury program had showed pronounced symptoms of a decrease in orthostatic stability, which lasted 19 hours after the flight (Berry, 1971). Taking this into account, the program of pre- and postflight investigations included special tests to determine the orthostatic stability (Table 5). In fact, a number of parameters indicated that the nature of the changes in the parameters of the cardiovascular system was the same both under orthostatic influences and under weightless /642
conditions. From this it is possible to predict that astronauts, with a certain degree of probability, will develop orthostatic instability under spaceflight conditions (Buyanov, Pisarenko, 1972, and others).

TABLE 5. METHODS OF EVALUATING THE ORTHOSTATIC STABILITY IN ASTRONAUTS PARTICIPATING IN THE GEMINI AND APOLLO FLIGHTS

Tests	Methods	Crew of the Spacecraft
Functional tests of antigravitational reactions of the cardiovascular system.	Passive method of standing.	All Gemini flights, Apollo-9, 10, 11, 12, 13, 14.
	NPLB method - negative pressure on the lower half of the body.	Apollo-7, 8, 9, 15, 16.
Pre- and postflight recording of physiological parameters.	Frequency of cardiac contractions. Blood pressure. Change in leg volume Roentgenography of the heart.	All Gemini and Apollo crews.

As a result of the planned investigation of the Gemini astronauts, a postflight decrease in orthostatic stability was detected, taking the form of accelerated heart beat, decrease in systolic and pulse pressure, increased tendency toward development of syncope while maintaining a vertical posture (Dietlein, 1970). It was found that the orthostatic stability decreased after the 14-day orbital flight of Gemini-7 to an extent that was no greater than after those flights that lasted a shorter time (1-6 days). As an illustration, Figures 7 and 8 show the data on the change in pulse frequency following spaceflights of varying duration (Figure 7) and the results of an examination of the commander of the Gemini-7, F. Borman. Figure 8 shows the increase in the pulse during the first postflight examination. Although a presyncopal state was not found, the pulse pressure decreased. The volume of the legs increased, indicating a significant plethora. Similar data were obtained in examinations in the Apollo program (Johnson, 1971; Dietlein, 1970; Berry, 1971). As a rule, during the first postflight examinations the creation of negative pressure on the lower half of the body or the test involving standing led to a speeding up of the frequency of cardiac contractions that was more than before the flight (Figure 9).

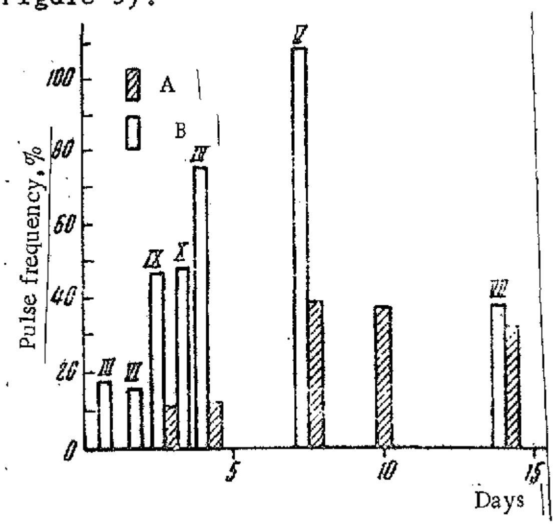

Figure 7. Change in Pulse Frequency (% of Data of Controlled Examinations, Average Values) in the Orthostatic Test in the Astronauts Following Flights Aboard the Gemini Spacecraft and in Subjects Following Bedrest Versus Duration of the Experiments: A, Experiments with Bedrest; B, Spaceflights, Roman Numerals -- Numbers of the Spacecraft.

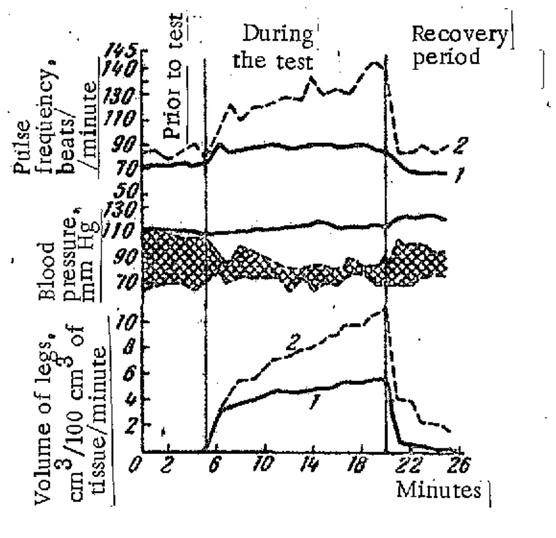

Figure 8. Physiological Reactions in the Commander of the Gemini-7 Spacecraft to the Orthostatic Test Before and After Flight Aboard the Gemini-7: 1, Before Flight; 2, After Flight.

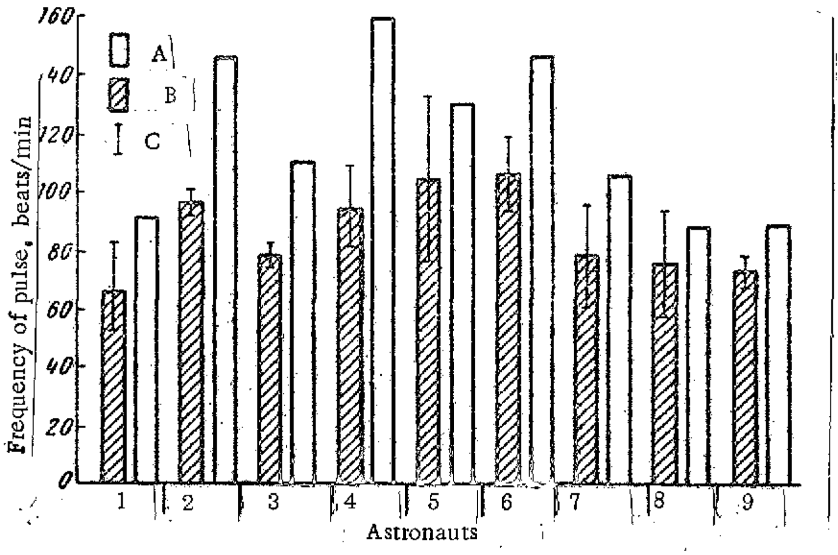

Figure 9. Maximum Level of Pulse Frequency (Beats/Min) in Several Astronauts Following Flights in the Apollo Program Under the Influence of Negative Pressure on the Lower Half of the Trunk: A, Results of Examination After the Flight; B, Results of Examination Before the Flight; C, Limits of Variation; 1, Schirra; 2, Eisele; 3, Cunningham; 4, Borman; 5, Lovell; 6, Anders; 7, McDivitt; 8, Scott; 9, Schwikert.

The changes in blood pressure during the orthostatic tests were not regular. In many cases the systolic and diastolic pressure decreased while in others they increased. However, the pulse pressure was reduced in all astronauts in comparison to preflight data (Figure 10). The variation in the sys- /643
tolic and diastolic pressure were characteristic. In those persons who were close to syncopal states during the test there was a significant drop in the pulse, systolic and (to a lesser degree) diastolic pressure and pronounced bradycardia.

During the flights of the Apollo-11, 12, 14 and 15 some of the astronauts spent a long period of time in weightlessness while others were exposed for a time to conditions of reduced gravitation (1/6 that on Earth), while carrying out various kinds of work (Table 1). In this connection it was interesting to compare the data on them concerning orthostatic stability. It was found in the case of the astronauts who walked on the surface of the Moon that ortho- /644
static stability did decrease but to a lesser extent than in those who were constantly exposed to weightlessness. The latter is illustrated by the results

of an examination of the Apollo-14 crew where S. Roosa -- the pilot of the control module -- did not walk on the lunar surface while the other crew members did so (Table 6). As we can see, in the case of astronauts A. Shepard and E. Mitchell, who were subjected to the lunar gravitation, the test of passive standing showed almost no changes with respect to preflight reactions. Roosa, on the other hand, showed a very marked increase in pulse rate and a drop in blood pressure. Moreover, in examinations conducted immediately following the flight and 12 hours afterward, he was observed to be in a pre-syncopal state. Of course, it is still too early to draw any final conclusions with respect to this question.

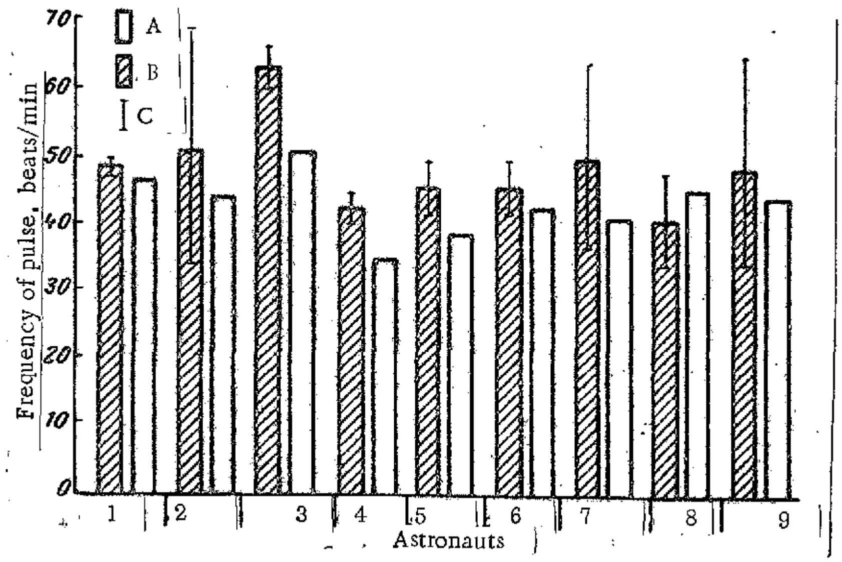

Figure 10. Pulse Pressure (mm Hg) in Certain Astronauts Following Flights in the Apollo Program Under the Influence of Negative Pressure on the Lower Half of the Trunk: A, Results of Postflight Examination; B, Results of Preflight Examination; C, Limits of Variation; 1, Schirra; 2, Eisele; 3, Cunningham; 4, Borman; 5, Lovell; 6, Anders; 7, McDivitt; 8, Scott; 9, Schwikert.

As was pointed out earlier, the functional state of the cardiovascular system during the postflight period was also evaluated through dynamic measurements of certain parameters (Table 5) in the astronauts in a state of rest, without functional tests. The most complete and interesting information regarding the results of these measurements for the Apollo crew members can be found in Johnson (1971). According to his data, the postflight examinations regularly showed a decrease in the perimeter of the shin in the astronauts in the course of examinations conducted immediately after splashdown. In all members of the Apollo-7, 8, 9, 10, 11 and 15 crews a reduction of the perimeter of the extremity was observed which amounted to 1.0 cm on the average (0.25--2.0 cm).

Roentgenography of the chest performed on 24 pilots in the Apollo program showed that 19 had undergone a decrease in the size of the heart shadow. The Gredel [Translator's Note: eponymic unknown] index (ratio of the transverse dimensions of the heart and lung) decreased by 0.01 in five, by 0.02 in two, by 0.03 in three, by 0.04 in six, by 0.06 in one and 0.1 in one astronaut. This amounted to 0.5-3 cm of the transverse diameter of the heart shadow. Among the crew members who conducted EVA's on the lunar surface, the changes were less and Armstrong (the commander of the Apollo-11) showed none at all. Examination of pre- and postflight pictures of the chests of the Gemini crew members showed the same feature: a decrease in the Gredel index and a change in the configuration of the heart shadow.

During the postflight examinations the clinical electrocardiograms taken /645
in a reclining position frequently showed a decrease in the T wave and slight (but noticeable) changes in the QRS complex. The astronauts aboard the Apollo--15 were the first to have the vector cardiograms recorded before and after the flights. In the spacecraft commander and the lunar module pilot, the same increase in the angle of separation of the QRS-T was observed. The T wave was displaced clockwise 30° from its centrally reduced and left-side direction. The QRS complex was enlarged in all three planes. The backwardly directed vectors, both sinistral and dextral, became noticeably greater. The only exception was the data from the command module pilot. The final portion of the QRS complex had a projection that was oriented more to the right and backward, while the loop of the T wave was directed slightly further backward and vertically in comparison with the value recorded prior to the flight. Similar vectorographic changes were indicative of a decrease in heart volume (Johnson, 1971).

TABLE 6. PARAMETERS OF THE REACTIONS OF THE CARDIOVASCULAR SYSTEM IN ASTRONAUTS ABOARD THE APOLLO-14: SPACECRAFT COMMANDER A. SHEPARD, COMMAND MODULE PILOT S. ROOSA AND LUNAR MODULE PILOT E. MITCHELL IN A PASSIVE ORTHOSTATIC TEST (AVERAGE DATA)

Astronauts	Preflight Data		Postflight Data							
			Immediately After the flight		After 12 Hours		After 24 Hours		After 36 Hours	
	Reclining	Standing	Reclin-ing	Stand-ing	Reclin-ing	Stand-ing	Reclin-ing	Stand-ing	Reclin-ing	Stand-ing
				Pulse Frequency, Beats/Minute						
A. Shepard	56 ± 3.6	74 ± 7.0	54	69	53	67	58	71	60	75
S. Roosa	63 ± 7.0	73 ± 6.7	80	91	83	95	79	104	77	100
E. Mitchell	65 ± 1.5	79 ± 4.6	63	86	67	86	69	91	71	89
				Systolic Blood Pressure, mm Hg						
A. Shepard	101 ± 0.6	108 ± 7.2	100	98	108	116	108	116	111	115
S. Roosa	120 ± 16.0	126 ± 16.0	123	129	116	98	118	118	112	115
E. Mitchell	111 ± 4.7	106 ± 4.5	113	104	119	107	112	95	117	111
				Diastolic Blood Pressure, mm Hg						
A. Shepard	60 ± 8.1	70 ± 15.3	68	75	71	81	70	70	66	67
S. Roosa	72 ± 7.4	86 ± 12.4	89	93	77	75	73	88	68	80
E. Mitchell	60 ± 7.5	62 ± 10.1	76	74	72	73	55	66	56	52

The pulse frequency and blood pressure recorded at rest were not constant in all cases. In 12 out of 21 astronauts there was a statistically reliable increase in pules rate in comparison with preflight data while in 9 there was practically no change.

In conclusion, it should be pointed out that the changes that were observed under weightless conditions involving the cardiovascular system constitute adaptive reactions to these unusual conditions. During the flights, there was no case of deterioration of cardiac activity. Changes involving the cardiovascular system became evident only after a return to conditions of terrestrial gravitation. During the postflight period there was an increased accumulation of venous blood, a speeding up of the cardiac contractions in the orthostatic tests (up to 150-170 beats/minute), a decrease in pulse pressure, and presyncopal states. The degree of the change and the duration of the recovery period depended to a certain extent on the duration of the flight but did not exceed 72 hours.

These changes must be closely linked to the disproportionately large capacity of the vessels relative to the volume of circulating blood and inadequacy of regulatory mechanisms, as supported by the significant variations in blood pressure that occurred during the postflight examinations. (To be continued.)

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